

Fired heaters in the process industries: Optimizing operations and minimizing emissions

The process industries, which include chemicals, metals and mining, oil and gas, petrochemicals, pulp and paper, and refining, are very energy intensive. In these industries, fired assets are the largest energy consumers and represent a tremendous opportunity for energy savings. Often referred to as a boiler or furnace, a fired heater is a heat exchanger that transfers heat from fuel combustion to process fluids. In refineries, the most energy intensive fired assets are thermal cracking furnaces, alkylation units, catalytic reformer units, catalytic hydrocracking heaters and steam methane reformers.

Fired assets have potential for improvement in many areas such as safety, energy efficiency, asset performance, asset lifespan and emissions reductions.

Particularly during startup and shutdown, a fired asset presents a major safety risk. Poor controls or lack of accurate monitoring of live conditions (e.g., excess fuel levels) within the fired asset could result in an explosion.

Erring on the side of safety, operators often attempt to minimize that risk by using excess air in the combustion process. However, this decreases fuel efficiency and leads to higher carbon dioxide (CO_2) and nitrous oxide (NO_x) emissions. Less than optimal controls could result in failures in the process equipment and reduced asset lifespans, as well.

By deploying a holistic methodology that consists of contemporary measurement and control technologies in conjunction with updated operation and maintenance procedures,

fired asset managers can realize significant improvements in energy efficiency, safety, asset performance and asset lifespan.

New developments in process instrumentation and analytical technologies have proven to enhance optimization of industrial fired assets, resulting in:

- Increased energy efficiency
- Protection of equipment and component investments
- Reduction of unscheduled production downtime
- Reduction in operation and maintenance costs
- Reduction in total cost of ownership
- Improvement in production quality and management of quantity
- Production effectiveness and repeatability
- Safety improvement
- Asset performance management improvement.

Key aspects influencing fired asset control. The authors' company created a process simulator to test the key aspects influencing fired asset control and to evaluate potential improvements. Key considerations in fired asset operations include excess air control, fuel composition changes, downstream pressure and temperature, feed composition, and rate and heat distribution between the convection and radiant sections.

Excess air control. Fired asset efficiency is strongly dependent on the excess air volume. Therefore, operators should optimize excess air to increase system efficiency. To ensure complete combustion, operators should provide more combustion air than is theoretically required. This tactic helps ensure safe operation by avoiding a fuel rich condition.

Since tunable diode laser spectroscopy (TDLS) technology can measure the amount of oxygen (O_2) directly in the radiant section of a fired asset on a 2 sec–4 sec cycle, the reference used in this study was the amount of O_2 instead of the excess air. Normally, there is a slight variation of excess air for different fuels, but the differences between maximum and minimum values for selected gases are below 1% and that could be mitigated (FIG. 1).

As shown in FIGS. 2 and 3, radiant efficiency correlates closely with the amount of excess air. Operators should optimize excess air to increase system efficiency and, for safety purposes, should provide slightly more combustion air than is theoretically required. However, observation shows that this is sometimes too much, as the density of the fuel gas is not always readily available to the operator. A combustion process

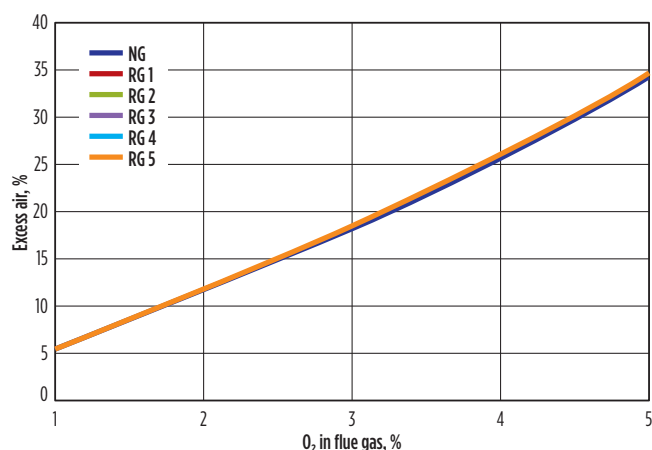


FIG. 1. Excess air for different fuel gas composition.

should have a balance between losing energy from using too much air (lean mode) and wasting energy from running too much fuel (rich mode).

The best combustion efficiency can be achieved at the optimum air-to-fuel ratio—controlling this provides the highest possible efficiency. The air-to-fuel ratio is burner specific and should be set by correctly considering the fuel composition and specific operational conditions.

Fuel composition changes. One major factor affecting fired asset performance is that refineries often use a mixture of natural gas and refinery gas as fuel. Refinery gas is a mix of gases generated during refinery processing. The composition of this gas fluctuates immensely and is strongly dependent on the composition of the crude oil and the refinery processes. Common components include butane, butylene, methane (CH_4), ethane and ethylene. To evaluate the potential impact of fuel composition fluctuations, the simulator used natural gas and evaluated five different mixtures (TABLE 1).

Downstream pressure and temperature. In a process unit such as a tower, which is often downstream of the first fired asset, a higher temperature increases the pressure in the process and, in return, influences evaporation inside the heater tubes, causing an additional disturbance to combustion control.

Feed composition and rate. The increasing popularity of blending has demonstrated that a transition from one crude type to another poses challenges. Scheduling can influence the feed rate, with changes made in very small steps.

When the feed is in line with desired throughput, variation of the outlet temperature and the behavior of the process flow distribution controller can cause additional disturbances to control stability. Variations in the inlet temperature of the feed could cause even further disturbances. It is not uncommon to see fluctuations of 10°C – 16°C (18°F – 29°F). Any overheating of the outlet coil temperature has a significant impact on the fuel consumption and leads to reduced efficiency. Altogether, it impacts the stability and safety of the operation and energy efficiency of the entire process.

Heat distribution between the convection and radiant sections. For fired assets such as vacuum heaters or thermal cracking heaters, it is mandatory to take into consideration the correct heat distribution and, as a result, the temperature

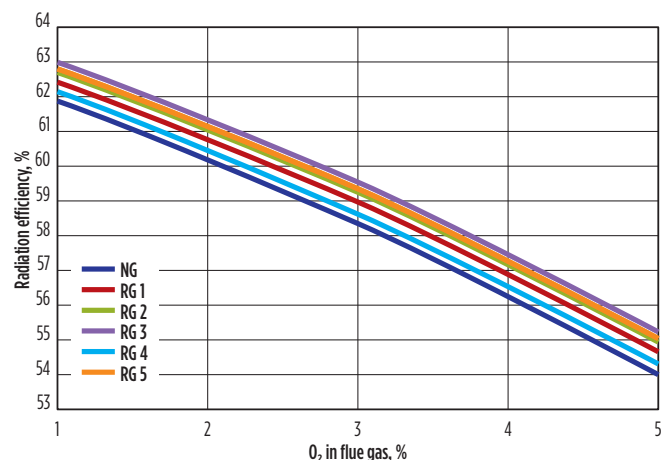


FIG. 2. Radiant efficiency for different fuel gas composition.

distribution along the tubes in the radiant and convection sections (FIG. 4).

The higher volume of excess air results in higher absorbed heat in the convection section and increases the crossover temperature. Given that the design heat transfer occurs in the radiant section, the resulting coil outlet temperature (COT) could be much higher. Assuming the COT will remain the same, automatic fuel input should adjust the fuel accordingly.

Consequently, there is a higher tube metal temperature in the convection section near the crossover. Due to a higher coil inlet temperature (CIT) for the radiant tubes, it could be pushed above the design temperature.

Tubes and tube supports are designed to the minimum thickness to be cost competitive, as the alloy tubes are typically very expensive. The design thickness depends on the design temperature profile. Higher temperatures require thicker tubes or possibly different tube material. If a furnace is running with higher excess air (i.e., higher CIT), the temperature profile will change and result in premature coking in the tube, or thermal cracking will start prematurely, creating an over-cracking condition. Tubes and tube hangers exposed to higher temperatures could prematurely fail. Therefore, it is very important to maintain the design tube metal temperature profile.

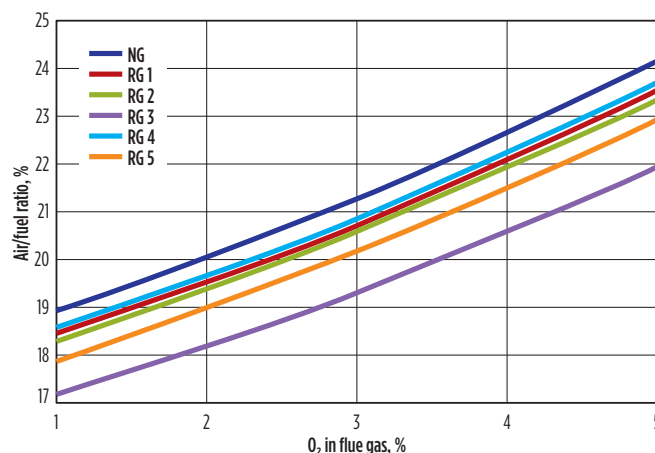


FIG. 3. The air-to-fuel ratio for different fuel gas composition.

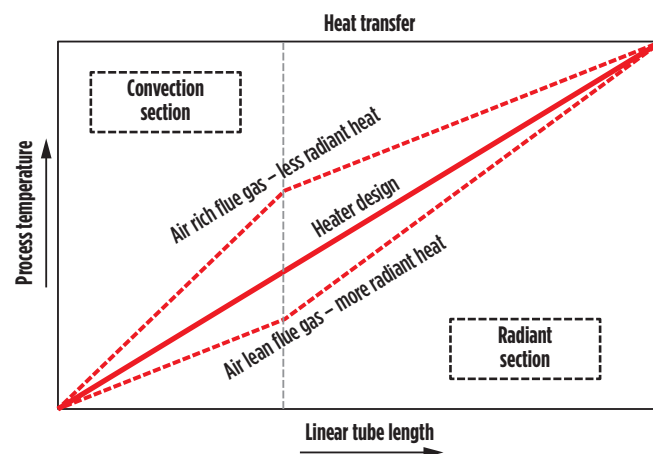


FIG. 4. Temperature profile inside the tubes for different operation conditions.

Monitoring the tube metal temperature creates a robust control to prevent overheating and assists the plant operator in plan-

understand system limitations or constraints that need to be addressed. These two steps provide the information needed to develop an ROI calculation and to determine the minimum required instrumentation that must be added.

The holistic methodology uses an analysis of existing loop control structures and surrounding conditions. Based on empirical and theoretical experience, it allows the fired asset control process to be finely tuned.

The holistic solution has also been proven to increase fuel efficiency, increase productivity, reduce NO_x and CO₂ emissions, reduce SCR NH₃ injection and increase asset and catalyst life spans. Operating the fired asset at the edge of the safe operating envelope with minimum excess air provides tangible benefits that maximize ROI.

Holistic solution measurement. Often, fired asset managers need only to add measurements, such as coil and tube temperatures, or replace aging instrumentation. Measurement capabilities include comprehensive

instrumentation with emphasis on TDLS for fast and accurate post-combustion gas analysis.

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Holistic solution^a for fired asset operations. Before applying and understanding the value of a solution, a holistic, comprehensive and collaborative effort must be applied that includes an engineering analysis of the fired asset to resolve the performance, operational and safety issues that are unique to the particular asset. Only then will the strategic application of hardware, software and turnkey project services provide a quantifiable return on investment (ROI) that adds value and improved reliability to the operation of the asset. This combines expertise in all areas of fired asset analysis, field device selection, optimization, and lifecycle maintenance and support to revolutionize operation of fired assets and combustion processes.

Post-combustion composition measurements are very important. Industry groups such as API 556 have recognized that the traditional approach to O₂ content measurement in combustion gases using zirconium oxide probes presents a safety hazard because they operate above the CH₄ ignition temperature. Since these probes cannot be in high-temperature radiant sections, they do not provide proper measurements in non-homogenous combustion gases. When placed after the convection section or in the stack, they often add long measurement delays that could be arbitrarily skewed by tramp air. Not only does the zirconium oxide technology present a potential safety risk, it also contributes to excessive fuel consumption, excessive emissions and decreased production.

A four-tiered approach allows fired asset managers to focus on the most appropriate improvement aspects. The holistic solution can be deployed in one or more tier levels that focus on analysis, measurement, control and optimization.

In contrast, a TDLS analyzer installed in the radiant section provides near-real-time O₂ and carbon monoxide (CO) measurements that are not skewed by tramp air. Depending on the fired asset application, additional live measurements by the TDLS analyzer could also include CH₄ and ammonia (NH₃).

Holistic solution analysis. Before performance and safety issues can be addressed, it is important to understand the underlying causes of the disturbance factors that are limiting performance or inadequately addressing potential safety issues.

In addition to TDLS, the solution could include instrumentation for measurement of burner balancing, fuel density, fuel flow and stack flow, wind compensation ring for stabilized stack flow measurements and continuous emissions monitoring (CEMS).

Development of a theoretical model of the fired asset can reveal the potential performance improvement that will prove the estimated ROI that system changes will provide. However, it is important to review long-term operational data to

Control capabilities. For control applications, the holistic solution can work in conjunction with existing combustion controls and burner management applications or replace outdated equipment, as needed. Control capabilities include

TABLE 1. Specification of selected gases for simulation

	NG	RG1	RG2	RG3	RG4	RG5
Low heating value, kJ/Kg	49,332.8	48,966.5	48,707.5	46,332.8	48,812.1	48,273
Hydrogen, mol%	0	22	27	39	11	37.6
THC H/C ratio*	3.978	3.556	3.111	3.087	3.788	3.519
TCW C/F**	0.738	0.715	0.754	0.669	0.718	0.648
Density, kg/m ^{3***}	0.678	0.665	0.834	0.716	0.669	0.558

* THC H/C ratio represents total hydrocarbons ratio of atoms of hydrogen on carbon

** TCW C/F ratio represents total carbon weight on total fuel weight (gram mol weights)

*** For reference and comparison, pure methane has a density of 0.668 kg/m³ under normal temperature and pressure [defined as 20°C and 1 atm (14.7 psia)]

advanced combustion controls with cross-limited CO/O₂, improved burner management, patented stack flow wind compensation and user interface updates such as graphics, historian and performance reports.

Optimization capabilities. A variety of transformation capabilities allow fired asset managers to take multiple steps that are well beyond improvements in measurement and control. Optimizations could be any combination of the following:

- Feedwater pH optimization
- NH₃ slip optimization
- Combustion optics
- Turbomachinery controls
- Plant master and energy optimization
- Startup/shutdown procedural automation to simplify operations and improve safety
- Digital twins and full plant performance improvement analytics
- Operator training simulators
- Remote diagnostics via secure cloud
- Full plant performance improvement analytics, before and after implementation.

Addressing key factors for fired asset operation. Some key factors for fired asset operation are temperature control, excess air control and addressing fuel composition changes.

Improved temperature control. Improved measurements for pressure and temperature, coupled with tighter controls, have allowed the holistic methodology to address three of the key factors:

- Downstream pressure and temperature
- Feed composition and rate
- Heat distribution between convection and radiant sections.

By reducing the fluctuation of the outlet temperature (FIG. 5), the safety margin in maintaining the stability of the downstream process could be increased. Consequently, it was possible to reduce the set point of the outlet temperature to reach the same safety margin without influencing the downstream process. Such action will result in reduced fuel consumption, while increasing the efficiency of the fired asset.

Substantially fewer trips and increased asset life result from stabilized COT and O₂ content in flue gas. For fired assets such as steam methane reformers, which utilize catalyst in the tubes, avoiding trips can be critical to extending the life of the catalyst and delaying an extremely expensive catalyst change turnaround.

Well-balanced burners reduce maintenance costs and allow longer run times between turnarounds. Balancing the burners and stabilizing the COT equalize the load and reduce aging of all radiant section components.

Reduced coking results in fuel savings and maintenance cost reductions. Stabilized combustion reduces tube deposits, which accelerate at high temperatures. By smoothing out temperature peaks, fired asset managers reduce the amount of decoking that is necessary and maintenance time required.

Excess air control. Operating the fired asset at the edge of the safe operating envelope with minimum excess air will bring tangible benefits. This translates into revenue; the ROI

can easily be calculated, therefore justifying the investment in safety improvements.

As proven by more than 10 European installations, the level of O₂ was reduced to 1% in flue gas for refinery gas and 2% for a combination of oil and gas. Therefore, the consumption of the fuel was reduced to 0.6%–4.2%, depending on the fired asset design and actual operating conditions. Usually, the concentration of O₂ in flue gas is kept at 2.5%–3.5%, but there are cases where the fired assets are operated above 4%. Additional savings could be generated by stabilization COT. Experience shows that an additional 2%–6% of the fuel consumption savings can be achieved (FIG. 6).

Tight excess air control also provides for significant emissions reductions. Reduced NO_x emissions will decrease the load or even eliminate the need for an SCR, and the corresponding NH₃ injections.

Considering the price of €6/t of CO₂ emissions, it would be possible to reduce emission by 1.5 t/hr for this specific simulated case, resulting in more than €70,000/yr. In the simulations performed, savings were generated in the range of 0.8 t–2.5 t of CO₂ for natural gas and fuel oil, stemming from a reduction in excess air and reduced fluctuation of the coil outlet temperature (FIG. 7).

Addressing fuel composition changes. A real-time heating value estimate enables continuous bias of the air/fuel ratio to stabilize combustion and heat transfer into the tubes. This significantly eases fired asset operation, while minimizing the

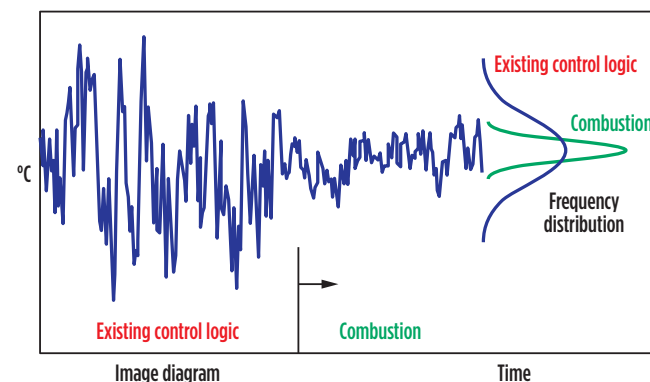


FIG. 5. Benefits of decreasing the magnitude of fluctuation of COT.

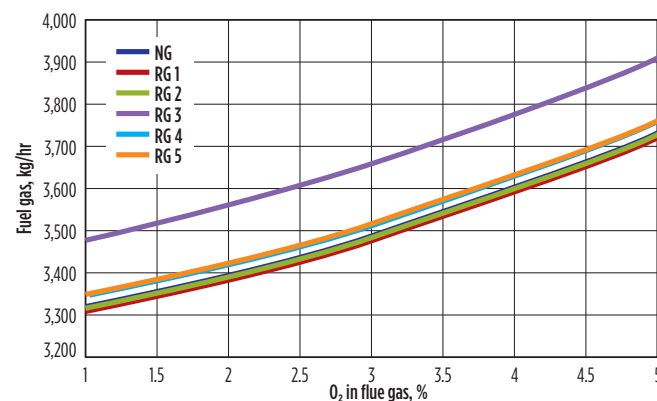


FIG. 6. Fuel consumption based on different fuel gas compositions and O₂ concentration in fuel gas.

thermal stresses on the tubes, even under conditions such as wide swings in demand or fuel heat value. The holistic solution was shown to enable safety improvements through the following measures:

- Detection of potential leakage from burner firing valves
- Detection of failures of pilot burners
- Replacement of flame sensor by utilizing TDLS or failure of flame sensors
- Trip prevention
- Reduction of the risk of liquid in gas piping
- Alarm derived from liquid level in fuel gas plant.

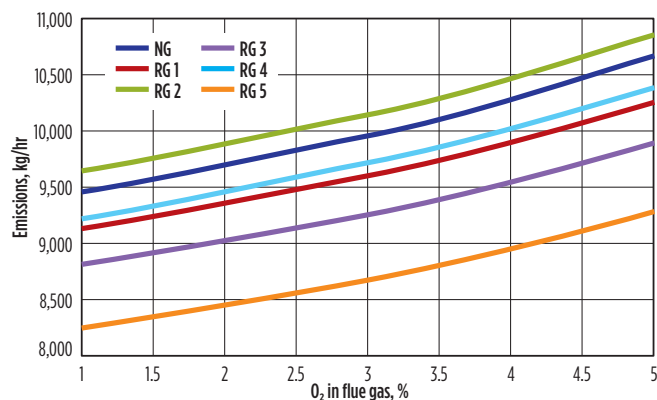


FIG. 7. CO₂ emissions based on different fuel gas compositions and O₂ concentrations in fuel gas.

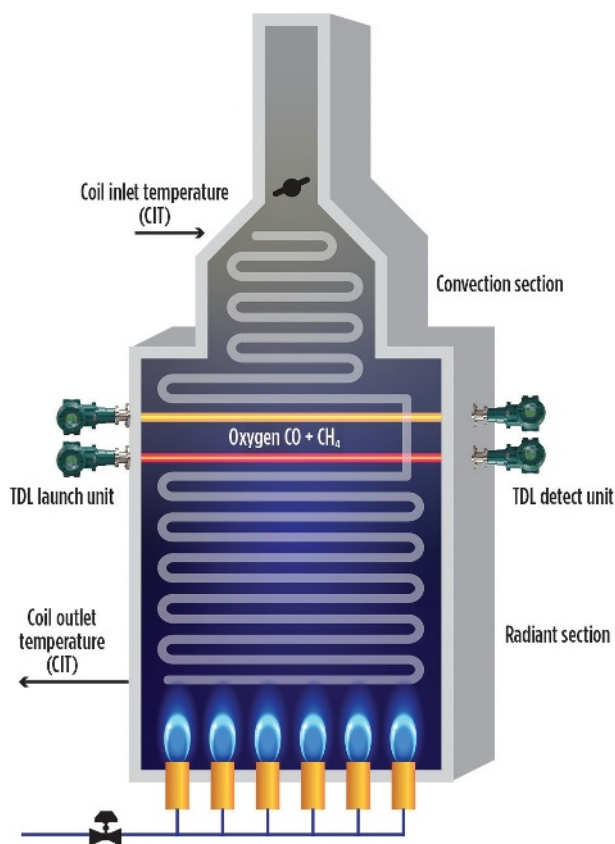


FIG. 8. Schematic example of utilization of the authors' company's TDLS technology.

APC vs. holistic methodology. In many cases, similar benefits could be achieved using advanced process control (APC). The implementation of APC is more time-consuming and requires higher investment. Additionally, special attention must be paid to the cycle time, which could result in the necessity for rapid disturbance response (e.g., CO excursion) on heater performance.

The major difference between APC and the holistic methodology is the increased safety of the fired asset by running it at the edge of the safe operating envelope with minimum excess air. Running at low O₂ without CO results in less combustion air (low excess air) being used, and less stack loss results in higher efficiency with the aim of reducing the risk of tripping. Tripping causes thermal shocks to tubes and refractory, which can increase the probability of component failures or premature replacement.

The holistic solution (**FIG. 8**) keeps focus on the following operating parameters/situations:

- Burner pressures tube skin temperatures, furnace draft, O₂, CO, fuel and air
- Automatically handles damper failure and potential operator mistakes
- Fuel valve failure.

If burners are air-limited, then higher throughput is possible with low excess air.

Takeaways. While controlling the COT under a variety of dynamic conditions provides many benefits to fired assets, the holistic solution^a can accomplish much more. As a trip prevention solution, it allows the fired asset combustion process to recover from any disturbance by slightly changing parameters based on predefined logic and monitoring the progress of recovery. Otherwise, the typical recovery procedure (should a trip occur) would take a minimum of 12 hr–24 hr, resulting in loss of production.

The holistic solution has also been proven to increase fuel efficiency, increase productivity, reduce NO_x and CO₂ emissions, reduce SCR NH₃ injection, and increase asset and catalyst life spans.

Operating the fired asset at the edge of the safe operating envelope with minimum excess air provides tangible benefits that maximize ROI. **HP**

NOTES

^a Yokogawa's CombustionONE solution



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fired asset and the resolution of performance issues by the strategic application of hardware, software and turnkey project services.